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should be left with only a few possible combinations left to consider. And you've discovered a heuristic rule — if you check the weather and your mood *first*, you can simplify the problem enormously.

Because some expert system "shells" are so simple, managers and technicians are taking AI out of the computer room and making it a viable local tool, much like spreadsheets made calculations a desktop phenomenon ten years ago. Expert systems are an enabling technology that makes possible the capture of knowledge rather than the display of computer number-crunching acumen.

KNOWLEDGE NAVIGATION

Another fundamental issue at the heart of AI is the issue of knowledge representation. The whole of AI hinges on not only how to look for information but also how to structure the information you're looking for. The simplest and most common represenation scheme is the IF/THEN statement of propositional logic. The 1,095-year chess strategy consists of a collection of complex and compounded nested IF/THEN statements. IF/THEN logic is also good for storing up expert system strategies based on experience: IF the lever is up AND the machine is stopped, THEN push the red button.

But to deal with generalities, you'll need to turn to predicate logic, the language of syllogisms and sets. You remember syllogisms: All men are mortal; John Sculley is a man; therefore, John Sculley is mortal. By comparing the category of things that are mortal with the category of things that John Sculley is, you discover an overlap and derive a new fact.

Other knowledge-representation techniques include semantic networks in which pieces of information are linked by a developer-created set of relationships like "a canary IS A bird" or "a hammer HAS A handle." Semantic networks help define relationships between objects.

I'VE BEEN FRAMED

Another representation method is the frame. Frames are places where stereotypical descriptions of THINGS are kept. If someone says BIG MAC, you perhaps think of two all-beef patties, special sauce, lettuce, cheese, pickles, and onions on a sesame seed bun. It would be hard to classify that description as a set of rules, so BIG MAC would be entered into the knowledge base as a specific example of the frame HAMBURGER. From HAMBURGER, the BIG MAC would inherit buns and meat. Other characteristics of the BIG MAC would be unique to its frame. If a knowledge-based system needed to know what comprised a BIG MAC, then one inspection of the BIG MAC frame would reveal all that needed to be known.

These techniques — propositional logic, predicate logic, semantic networks, and frames — establish the baseline upon which AI systems are built. If things are built, then they need a set of raw materials. In knowledge-based systems, those raw materials are called Prolog and LISP, two of the most popular languages for AI software development. See the sidebar "The Language of AI" for an overview of these and other widely used AI environments.

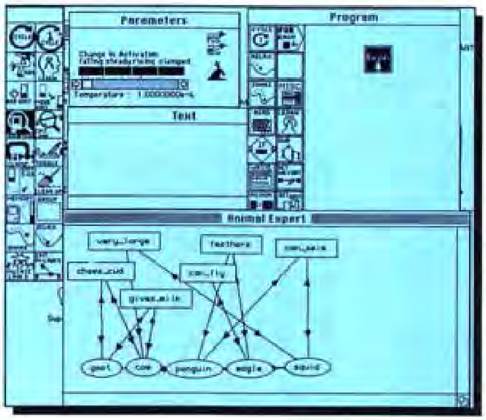
SPEAKING OF LANGUAGE

The languages many AI programmers would rather use, however, are English, French, and Japanese. So-called *natural-language processing* is one of the most widespread goals of AI.

The processing of natural language comes in two forms: speaking and understanding. Anyone familiar with Talking Moose, that ubiquitous desk accessory with the wise-cracking antler-head, knows that a Macintosh can speak English. Most typists acquainted with Microsoft Word know equally well that a Macintosh cannot understand English. It is the understanding of words, contexts, and meaning that drives AI researchers.

Simulating human speech by translating the 39 phonemes of American English was a simple task compared to the immensity of teaching a computer to understand a simple typed phrase like "Did the wind wind the kite string through the window?" How can the computer distinguish *wind* (the noun) from *wind* (the verb) from *wind-* (the syllable)? The job is even harder if you want to speak, rather than type, to your computer. It's possible for computers to "listen" to a sentence, digitize and capture the sound waveforms, pick out the component phonemes, and compare those sounds with a dictionary that lists words as combinations of phonemes. But how can a computer know whether you said *illegal* or *ill eagle?*

The answer is context. Suppose you say the phrase "illegal U-turn." Since U-turn is a noun, the adjective *illegal* probably makes more sense in front of it than the noun phrase *ill eagle*. Unless you're telling someone to turn around when they see a sick bird in the



MacBrain simulates the complexity of the human brain through a technology called *neural networks*. This example shows the classic animal identification expert system described as a semantic network. The nodes are small independent agents that learn by example.

The Language of AI

The Macintosh's popularity is growing in the AI community but doesn't yet have the same breadth as that of its big blue cousin. In programming languages, however, the Mac can hold its own.

Second only to FORTRAN, LISP has stood the test of time. This highly parenthesized language is the basis for most expert systems, as well as many natural-language and vision systems. LISP is the backbone of the AI community.

LISP stands for LISt Processor. Everything in LISP is a list. Data is contained in lists. Programs are contained in lists. In fact, there is no distinction between data and programs. At one point in a program's execution, a symbol may represent the number 2. A few moments later that same symbol may represent the program string `'(CAR(CDR(X,Y,Z)))`. To programmers who were brought up in the highly structured fraternity of Pascal or C, LISP seems like an orgy of bad programming techniques. This rambunctious language does what few languages do: It talks to itself. The power of recursion is embedded in the very nature of LISP. If you are to write intelligent systems, they must be able to call on images of themselves that are slightly different depending on the circumstance. LISP also has the ability to modify its own code. Isn't self-modification a test of intelligence?

Many variations have arisen from John McCarthy's original LISP. LISP is a language made for extension. It's also a place to write other languages. From this capability came Prolog.

Prolog was developed in France in 1973 and is the language of choice for Japan's national Fifth Generation computer project. Prolog is a programming language that has built-in backward chaining and — because it is designed around predicate logic — representational structure.

Excellent LISPs are available on the Macintosh, including Allegro Common LISP from Coral Software and ExperCommon Lisp from ExperTelligence, Inc. A public-domain version of LISP called XLISP by David Michael Betz is available on CompuServe and GEnie. Prolog is represented on the Macintosh by LPA MacProlog, AIS Prolog, and other less complete packages.

Other languages that have proven to have worth as AI investigation tools include POP-11 from the University of Edinburgh and Smalltalk from Xerox PARC. POP-11 has made a recent Mac appearance in the form of AlphaPop, from Britain's Cognitive Applications.

The more common C, Pascal, and Assembly languages have also proven to be popular for developing AI products on the Mac. The Macintosh is first and foremost a business machine that requires marketable applications, not development systems, and these languages are more familiar and easier to use for many programmers. The concepts and techniques, however, for C- and Pascal-based AI products on the Mac owe their history and existence to LISP and Prolog.

road: "After the ill eagle, you turn." In short, context is the key, but context is a complicated beast.

Our simple understanding of English is based on not only what we know of words but also a million moments of memory that tie those words to meanings. If you have ever watched the Benny Hill Show and tried to fathom some of the British-laden jokes with your American sensibilities, you have some understanding of what it is like to teach a computer to understand English.

Natural-language processing has been somewhat neglected on the Mac. On other machines with less friendly interfaces, the demand for a better way to communicate with the machine has led to a landslide of add-ons and products, like Q&A, HAL for Lotus 1-2-3, and Genifer for dBASE III. When natural language becomes more plausible developers will, no doubt, be asked for word processors that can be dictated to. The day will come.

To deal with natural language, computers must be taught to deal with ambiguity, imprecision, incompleteness, and inaccuracy. The bits and pieces that we hear are often not complete, but our brains help fill in the blanks by applying stereotypes of knowledge to the missing pieces. Frames are often used for natural-language processing. The best systems, though, are capable of understanding only a few thousand words; within that understanding, context is difficult to establish. Natural language faces the same struggle as other AI disciplines: understanding. Until a computer can understand what you want, it will be difficult to turn knowledgeable idiots into intelligent devices.

SEEING IS BELIEVING

A child is flooded with information. The smell of sweat on its mother's body, the light reflecting off its father's glasses, the touch of grandma's hand and the cool taste of fresh milk all feed information into the memory banks of a child. The senses of smell, touch, and taste are things electromechanical sensors can only approximate. Your household smoke detector cannot tell the difference between the smoke of a life-threatening fire and that of a skillet of overcooked eggs. Artificial intelligence researchers are inching closer to systems that can turn the reflected light of table edges and eyebrows into digital pictures that a computer can comprehend.

Like natural language, vision systems are in their childhood. But many manufacturing companies are already putting vision systems in place for quality control or precise adjustments of delicate parts. These vision systems are trained to recognize certain features of an object. The feedback from these objects is translated into a computer that can detect the edges of the object and feed that information into a program that knows what to do with a particular arrangement.

Automatix Corporation has recently announced a vision system that works with its industrial-strength Macintosh, the AI 90. Autovision 90 uses the Automatix Standard Application Package and MacRAIL application development languages, cameras, and an AI 90 Macintosh for creating manufacturing applications.

The early image digitizers that turned your Mac into a what-you-see-is-what-you-get MacPaint processor saw the world as a series of dots or shades of gray. In addition to static images, AI researchers must address the interpretation of color, depth, tex-

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ture, and motion. Some vision systems use models of real-world objects to provide the vision interpreter with a sample of what it should look for.

PERCEPTIONS AND PERCEPTRONS

Many AI researchers look to their creations as ways to expand our knowledge of the universe by enabling computers to do things people cannot do. The most challenging task for these scientists is teaching machines what humans *can* do: think. The representation schemes discussed earlier help translate learned experiences into computer-readable form. But many things that we do simply can't be expressed as lists of rules. Telling (or understanding) a joke, for example, defies description using a systematic set of rules, as any stand-up comic could tell you.

An alternative approach called *neural networks* has developed out of theoretical work in the 1950s (when this concept went by the name of *perceptrons*). These standard hardware programs simulate parallel processing agents to model the intense interconnectivity that takes place in the human brain.

Neural networks arrived on the Macintosh in the form of a much-flawed program called MacBrain. This program implements neural network algorithms that go by the ominous-sounding names of Hebbian/Hopfield, Back Propagation, and the Boltzmann Machine. Although the program is poorly implemented, it can help demonstrate the pattern-recognition abilities of neural networks.

Like children learning right from wrong, neural network systems are given an example of something and asked to identify it. If the identification is wrong, a kind of computer switch stick is used to direct the program toward the correct identification. As more examples are shown, the system is given positive reinforcement toward finding the right solution. Once the solution is embedded, it has another annoying similarity to human behavior: Neural nets are hard to break of a bad habit. When a rule-based system makes a wrong choice, you change a rule. When a neural-net system makes a wrong choice after hours of learning, it is very difficult to get it to change its behavior.

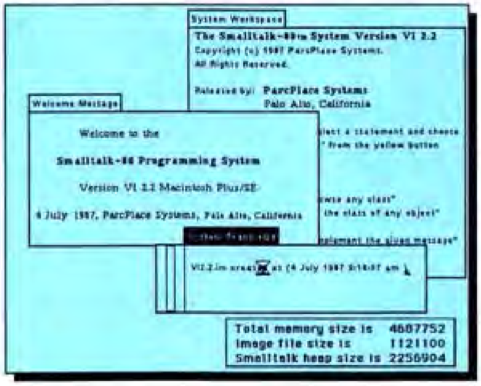
Neural networks are not the answer to the "understanding problem" in AI, but they may prove to be the technology that brings the sensory input to the computer in a way that is understandable.

THE OBJECT OF IT ALL

One of the most exciting new AI tools is object-oriented programming. The concept of Mac windows comes from the world of object-oriented programming. At a recent conference, noted AI lecturer and author Avron Barr called the Macintosh an "AI Machine" because of its intelligent interface. What is really happening behind those windows is message passing, and message passing can be applied in areas a lot more diverse than windows.

Object-oriented systems are an alternative to long, complex programs that have a huge overhead and an impossible sense of complexity. In the object-oriented world you create representations of real-world things, and those things have the knowledge or procedures they need embedded in them. Then they talk to each other.

Smalltalk, the language that inspired the Macintosh interface, is the premier object-oriented language where the passing of messages takes the place of conventional looping and iteration. Smalltalk comes to the Macintosh as Smalltalk-80 from ParcPlace Systems. This full implementation of Smalltalk provides a wonderful new world for AI enthusiasts and a completely different reality for programmers familiar with C or Pascal. Another less extensive version of Smalltalk is available to members of APDA. And



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The Smalltalk-80™ System Version VI 2.2
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Released by:  ParcPlace Systems
              Palo Alto, California

Welcome to the

Smalltalk-80 Programming System

Version VI 2.2 Macintosh Plus/SE

4 July 1987, ParcPlace Systems, Palo Alto, California

Total memory size is    4607752
Image file size is      1121100
Smalltalk heap size is  2250904
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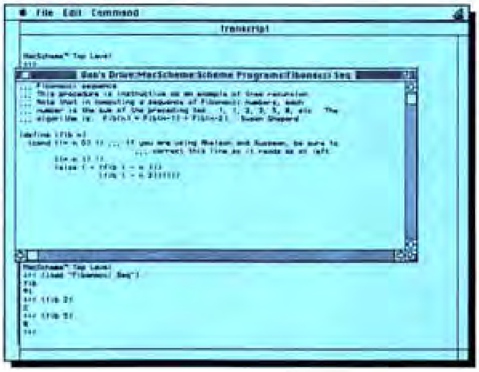
The Smalltalk environment displays the origins of the Macintosh. Developed at the Xerox Palo Alto Research Center, Smalltalk introduced many advanced features like message passing, windows, and intelligent objects.



Artificial Intelligence is full of computer tricks. One of the most useful is called *recursion*. In this screen shot, Semantic Microsystem's MacScheme uses recursion to solve the Fibonacci numbers equation.